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**CONTROL/STRUCTURE INTERACTION METHODS FOR SPACE STATION POWER
SYSTEMS**

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ABSTRACT

The Structural Dynamics Research Corporation and the NASA Lewis Research Center have been working together to develop tools and methods for the analysis of control/structure interaction problems related to the space station power systems. Flexible modes of the solar arrays below 0.1 Hz, suggest that even for relatively slow control systems, the potential for control/structure interaction exists. The emphasis of the effort has been to develop tools which couple NASTRAN's powerful capabilities in structural dynamics with EASY5's powerful capabilities in control systems analysis. One product is an interface software package called CO-ST-IN for Control-Structure-Interaction. CO-ST-IN acts to translate data between NASTRAN and EASY5, facilitating the analysis of complex coupled problems. Interfaces to SDRC I-DEAS and MATRIXx are also offered. Beside transferring standard modal information, CO-ST-IN implements a number of advanced methods. These include a modal ordering algorithm that helps eliminate uncontrollable or unobservable modes from the analysis, an implementation of the more accurate mode acceleration algorithm for recovery of element forces and stresses directly in EASY5 and an implementation of fixed interface modes in NASTRAN, which reduces the error in the closed-loop model due to the use of truncated mode sets. A brief overview of the program will be presented, along with description of some of the methods used to facilitate rapid and accurate analyses.

CONTROL/STRUCTURE INTERACTION METHODS FOR SPACE STATION POWER SYSTEMS

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AGENDA

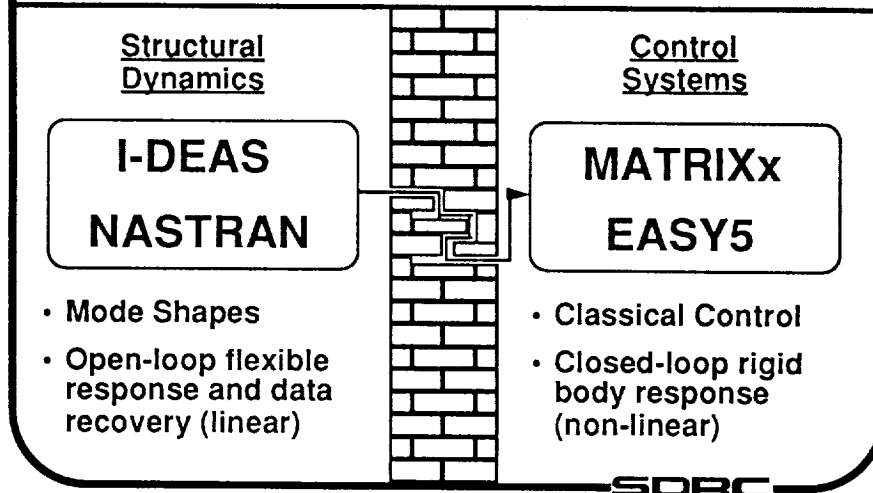
- Quick Overview of CO-ST-IN Program
- Alternate Modal Representations
- Discussion

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NOTES

SDRC has been working with the NASA Lewis Research Center to develop methods for the study of control/structure interaction problems related to space station power systems. We will discuss the software developed for this project, (CO-ST-IN) and if we have time we will briefly mention the important area of alternate modal representations to improve the accuracy of closed-loop models.

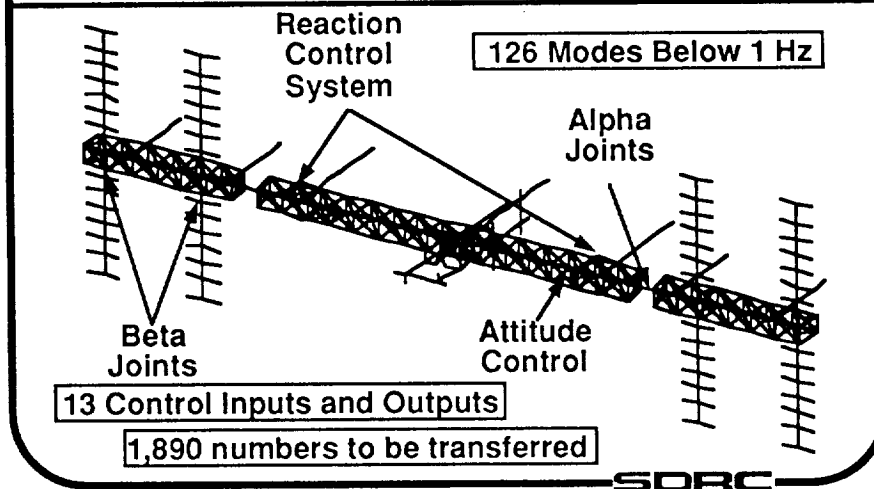
DATA NEEDS TO BE TRANSFERRED FROM STRUCTURES TO CONTROLS



NOTES

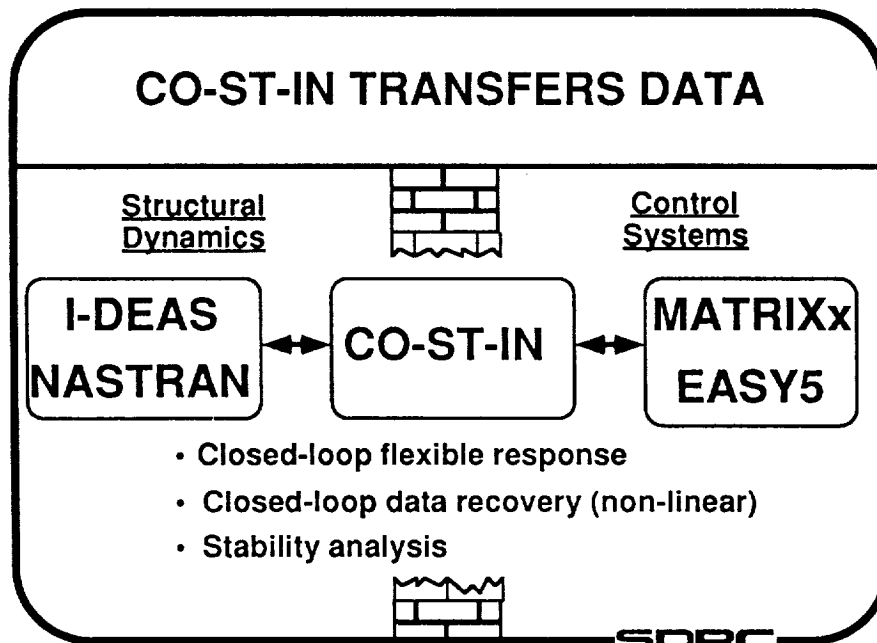
Standard approaches to Control/Structure Interaction problems combine two separate disciplines, structural dynamics and control systems. Data is often passed manually from engineers in one group to engineers in the other. Furthermore, each group uses its own analysis tools. We use I-DEAS and NASTRAN for structural dynamics and MATRIXx and EASY5 for control systems.

SPACE STATION MODEL TOO LARGE FOR MANUAL TRANSFER OF DATA



NOTES

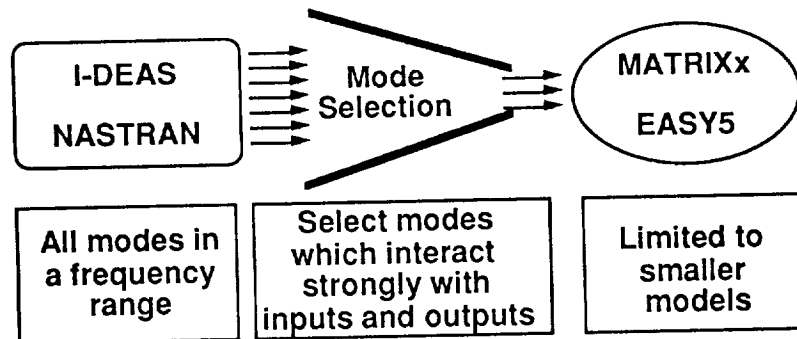
The space station is a large complex structural system with a large number of closely spaced, low frequency modes and a large number of structural inputs and outputs. The size of the model makes manual transfer of data impractical. Model size also puts a large emphasis on practical model reduction algorithms.



NOTES

CO-ST-IN stands for **CO**ntrol-**ST**ructure-**IN**teraction. It automates the transfer of data back and forth among I-DEAS, NASTRAN, MATRIXx and EASY5. CO-ST-IN implements a number of special (non-standard) capabilities as well as the automated transfer of modal data.

MODAL ORDERING REDUCES MODEL SIZE

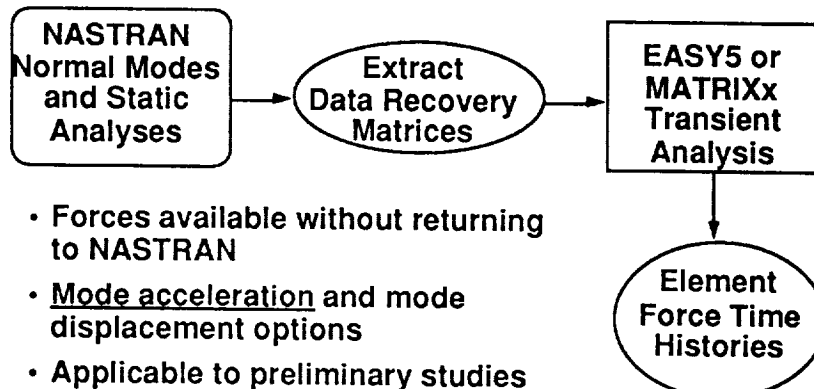


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NOTES

Since many control system algorithms fail for large models it is essential to select as small a model as possible. Large structural models usually contain a number of modes which do not interact significantly with inputs and outputs. Modal ordering can help eliminate these modes, resulting in an accurate reduced order model. We implement both Skelton's modal cost and the approximate balanced singular value as measures of modal influence. Inputs and outputs can be scaled to reflect their relative importance, and modes can be grouped when modal frequencies are close.

ELEMENT FORCES CAN BE CALCULATED IN EASY5 OR MATRIXx

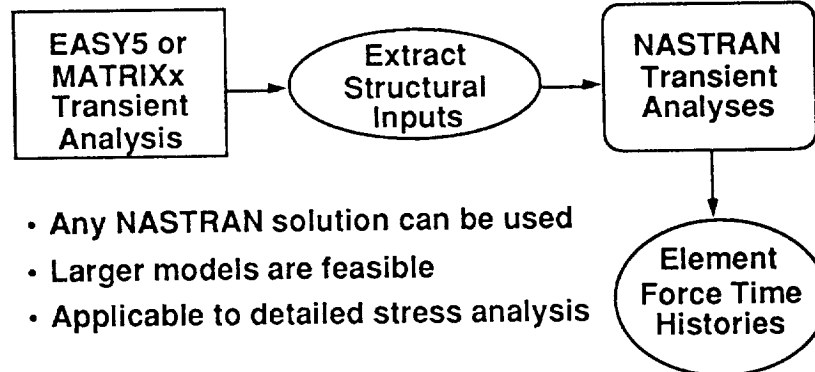


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NOTES

Calculating element forces and stresses directly in the control system routine can greatly accelerate turn around time. We transfer the appropriate matrices from NASTRAN to let us implement a mode acceleration technique. The mode acceleration formulation adds a static correction term to the standard mode displacement formulation which improves accuracy when using truncated mode sets. This approach is applicable to parameter studies, where quick turn around time is paramount.

ELEMENT FORCES CAN BE CALCULATED IN NASTRAN

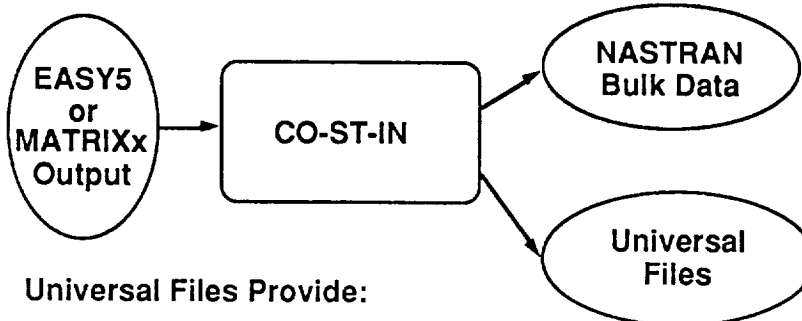


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NOTES

Detailed stress analyses fall into the realm of structural dynamicists. In order to facilitate the direct application of NASTRAN to this problem we extract the structural input forces from the controls routine and write these as NASTRAN bulk data. This allows the structural dynamicist the flexibility to choose any NASTRAN transient technique (including a direct transient) to recover element forces and stresses. This method increases turn around time, but is applicable to a detailed stress analysis after control system parameters have been fixed.

CO-ST-IN TRANSLATES EASY5 AND MATRIXx OUTPUT



Universal Files Provide:

- Flexible plotting options
- Data management (SYSTAN)

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NOTES

As well as provide input to NASTRAN, other reasons for translating control system output include the requirement for more flexible plotting and data management. By translating time simulation output to I-DEAS Universal file format, we can store functions in a database, facilitating the application of powerful data management and plotting capabilities.

CO-ST-IN IS A TOOL FOR CONTROL/STRUCTURE INTERACTION

- Transfers data between structural dynamic (NASTRAN and I-DEAS) and control system software (EASY5 and MATRIXx).
- Uses modal ordering to reduce model size.
- Data recovery performed directly in controls routine using the more accurate mode acceleration method.
- EASY5 and MATRIXx output translated for plotting, data management and NASTRAN data recovery.

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NOTES

CO-ST-IN is simply a tool for transferring data among otherwise incompatible analysis programs. CO-ST-IN tries to be smart in what it transfers by using modal ordering to reduce model size and a mode acceleration technique to recover element forces and stresses directly in the controls routine. Control routine output is translated to I-DEAS Universal file format in order to facilitate data management and plotting.

AGENDA

- Quick Overview of CO-ST-IN Program
- Alternate Modal Representations
- Discussion

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NOTES

The main focus of our investigation has been to determine the best possible structural models to use in control/structure interaction study. Here we define best to mean those which result in the most accurate closed-loop models while using a minimum number of dynamic states. This investigation has led us to examine the use of alternate (other than normal) modal representations.

FIXED INTERFACE MODES REPRESENT EFFECT OF INPUT FORCES

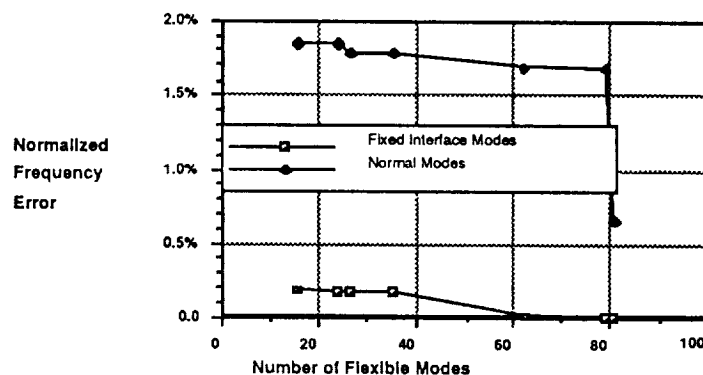
- Normal modes are calculated on basis of free-free boundary conditions
- Normal modes do not represent effect of input forces
- Fixed interface (cantilever, Craig-Bampton) modes result in more accurate closed-loop models
- Improvement even for "soft" controllers
- More pronounced for "stiffer" controllers

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NOTES

The basic problem with normal modes is that they are calculated on the basis of free-free boundary conditions. The result is that these modes poorly represent the local effects of forces and moments applied by control actuators at these boundaries. The use of fixed interface modes (sometimes called cantilever or Craig-Bampton modes) can help alleviate this problem by providing an accurate static representation at the location of control inputs. We have found that the use of fixed interface modes does result in more accurate closed-loop models, even for control frequencies which lie well below flexible frequencies. For stiffer controllers the differences are even more pronounced.

CLOSED-LOOP FREQUENCIES MORE ACCURATE

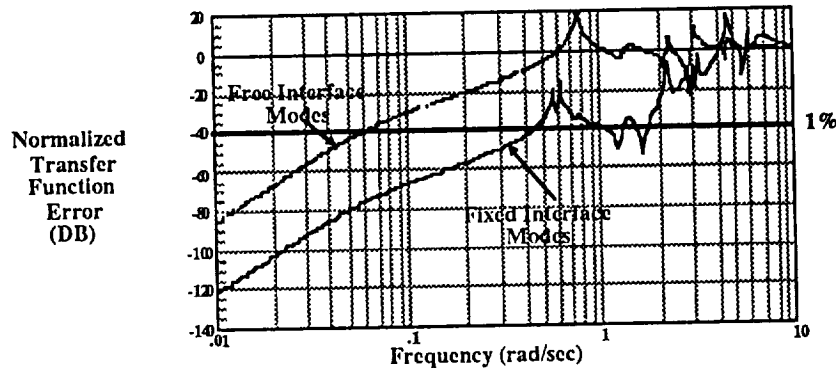


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NOTES

One measure of accuracy for the closed-loop model is the accuracy of closed-loop frequencies. Normalized error is defined as the distance of the approximate frequency from the exact frequency, divided by the magnitude of the exact frequency. In this case we are examining the accuracy of an alpha joint control frequency as we increase the number of open-loop modes, using either a fixed interface or a normal modes representation. In this case control frequencies are close to an order of magnitude below flexible frequencies and the results are consistent with other models that we've looked at.

CLOSED-LOOP FREQUENCY RESPONSE MORE ACCURATE



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NOTES

Another measure of accuracy for the closed-loop system is accuracy of the closed-loop frequency response. Here we examine the frequency response from an attitude command about the y-axis (roll) to response about the same axis. Normalized error at each frequency is defined as the distance of the approximate to the exact frequency response, divided by the magnitude of the exact response. Note that both representations are inaccurate at high frequencies (where modes are neglected), but that the fixed interface representation is more accurate at lower frequencies. The control frequency in this case is more than an order of magnitude lower than the flexible frequencies and again the results are consistent with other models we've examined.

SUMMARY

- CO-ST-IN transfers data between NASTRAN, IDEAS, EASY5 and MATRIXx
- Modal ordering reduces model size
- Mode acceleration data recovery performed in control simulation
- Fixed interface modal representations result in more accurate closed-loop models

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NOTES

Our work with NASA Lewis is on-going, and we will be continuing to develop methods which facilitate fast and accurate closed-loop structural analyses. We will also continue to place emphasis on the selection of improved structural representations for control/structure interaction studies.

A Brief List of CO-ST-IN Commands -

DAMP	- Define modal damping ratios.
DMPDAT	- Write all data to an unformatted file.
DRSC	- Scale data recovery outputs for modal ordering.
GYRO	- Define gyroscopic forces due to a spinning body.
INPT	- Define an absolute or relative structural input.
INPT1	- Define a generalized structural input.
INSC	- Scale inputs for modal ordering.
MACC	- Define an absolute or relative acceleration measurement.
MASC	- Scale acceleration measurements fro modal ordering.
MDSP	- Define an absolute or relative displacement measurement.
MDSC	- Scale displacement measurements for modal ordering.
MVEL	- Define an absolute or relative velocity measurement.
MVSC	- Scale velocity measurements for modal ordering.
OACC	- Define an absolute or relative acceleration output.
OASC	- Scale acceleration outputs for modal ordering.
ODSP	- Define an absolute or relative displacement output.
ODSC	- Scale displacement outputs for modal ordering.
OGRP	- Group modes for ordering.
ORDER	- Order modes on the basis of approximate balanced singular values.
ORDUSR	- User-defined modal ordering.
OVEL	- Define an absolute or relative velocity output.
OVSC	- Scale velocity measurements for modal ordering.
PARAM	- Define various problem parameters.
PID	- Define a PID controller.
PULSE	- Define a pulse train input.
REDDAT	- Read unformatted data file written by DMPDAT.
RCS	- Define a simple reaction control system for space station reboost.
RDRM2	- Read data recovery matrices from a NASTRAN Output2 file.
RDRM4	- Read data recovery matrices from a NASTRAN Output4 file.
RMN2	- Read modal data from a NASTRAN Output2 file.
RMU	- Read modal data from an I-DEAS Universal file.
RRESP	- Read response time histories from an EASY5 Plots file.
STITLE	- Define a problem subtitle.
TITLE	- Define a problem title.
WDRM4	- Write data recovery matrices in NASTRAN Output4 format.
WEAD	- Write an EASY5 Analysis Definition File.
WEMG	- Write an EASY5 Model Generation File.
WLODN	- Write NASTRAN FORCE and MOMENT cards for static solution.
WMATX	- Write matrices in MATRIXx format.
WRSPN	- Write structural input force response as NASTRAN Bulk Data.
WRSPU	- Write EASY5 responses in I-DEAS Universal File Format.

